Timing and causes of death after injuries

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Currently, long-term outcomes are significant because health care system changes will likely lead to a single payment for each occurrence of care, including readmissions—the "bundled payment" system. Therefore, it is essential to understand the outcomes of trauma patients discharged alive from trauma centers. This article reviews the current knowledge base on the timing and causes of deaths after trauma. The trimodal mortality model (immediate deaths, early deaths, and late deaths) is utilized as the early research describing trimodal distribution is discussed. Also covered is the successive work as trauma systems matured, showing a shift toward a bimodal distribution with a decline in late deaths. Finally, studies of long-term outcomes are highlighted. Deaths occurring within minutes or a few hours of injury are largely unchanged, which underscores the enormity of injuries to the central nervous and cardiovascular systems. Late deaths caused by multiple organ failure and sepsis have declined considerably, however. Also, the causes of death in this patient population remain constant. Lastly, a considerable number of deaths after discharge may be due to nontraumatic causes.

Survival to discharge has long been the primary endpoint for research and quality improvement in trauma (1, 2). More recent studies have begun assessing long-term outcomes such as complications, costs, readmissions, and survival after discharge (3–11). We have recently shown that over a period of 1 year after the initial injury, about half of the deaths occur within the first 30 days but the rest occur afterward (12). It is important to understand the outcomes of trauma patients discharged alive from trauma centers. Baker et al and Trunkey defined timing of trauma deaths as a trimodal distribution in urban environments in the United States (13, 14). However, the development and maturation of regionalized trauma networks in the 1970s and 1980s have shifted the epidemiology of trauma patients and patterns of mortality. Subsequent research has shown a decline in deaths late after trauma, indicating that the trimodal concept may no longer be accurate in urban trauma environments (12, 15–18). A confounding factor is inconsistent time intervals chosen by researchers to define the timing of deaths (18–20). Herein, we review the existing knowledge on timing and causes of deaths after trauma. We use the trimodal mortality model to cover the early research describing the trimodal distribution, the subsequent work as trauma systems matured, and studies of long-term outcomes.

TIMING OF DEATHS

The first peak in the classic trimodal model of trauma mortality is immediate death occurring within minutes of the injury. These patients are declared dead on the scene or die shortly after arrival to the hospital. In most published reports, these include deaths at the scene, deaths occurring within 1 hour of arrival to the hospital, and all deaths in the emergency department. These deaths are generally a consequence of severe and likely nonsurvivable injuries. The seminal works of Baker et al and Trunkey in the 1970s showed that 64% and 53%, respectively, of trauma deaths occurred on the scene, with the patients not even transported to a hospital (13, 14). *Figure 1* displays a summary of studies evaluating immediate deaths (12, 13, 15, 16, 18, 19, 21–24). This recognition led to rapid development of regionalized trauma systems in the United States, led by the work of Dr. Cowley in Maryland (25, 26). The primary purpose of regionalized integrated care was rapid transportation of patients from the scene to definitive care. It is interesting

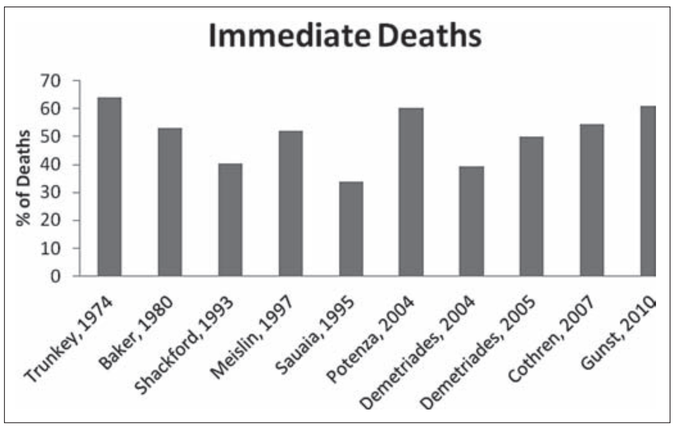

Figure 1. Studies reviewing immediate deaths (12, 13, 15, 16, 18, 19, 21–24).

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to note in Figure 1 that despite all the progress in emergency medical services and trauma systems, prehospital care, injury prevention, and automotive safety, the proportion of deaths occurring immediately after injury has remained unchanged over time, at 50% to 60%.

The second peak in the trimodal distribution is early deaths, defined as deaths within hours of arrival to the hospital. In most published reports, early deaths include deaths within 24 hours of arrival to a trauma center, excluding immediate deaths. These deaths are also a consequence of severe injuries, but the patients arrive at the hospital alive and are potentially treatable with prompt definitive care. Trunkey estimated this group to include approximately 30% of deaths (14). *Figure 2* depicts a range of studies evaluating early deaths (12, 13, 15, 16, 19). Again, the proportion of deaths in this group has remained relatively unchanged over time, at 25% to 30% of all trauma deaths.

In Trunkey's original description of the trimodal distribution, 20% of trauma deaths were "late deaths," defined as those occurring days to weeks after the injury among patients who survived the initial insult (14). In most reports, this category includes deaths occurring after the first 24 hours and all other in-hospital deaths. *Figure 3* displays studies evaluating late deaths (12, 13, 15, 16, 19, 22–24). In contrast to the first two categories, there has been a definite and dramatic drop in late deaths over time. In the most recent study by Gunst and colleagues, this group included only 9% of deaths (12).

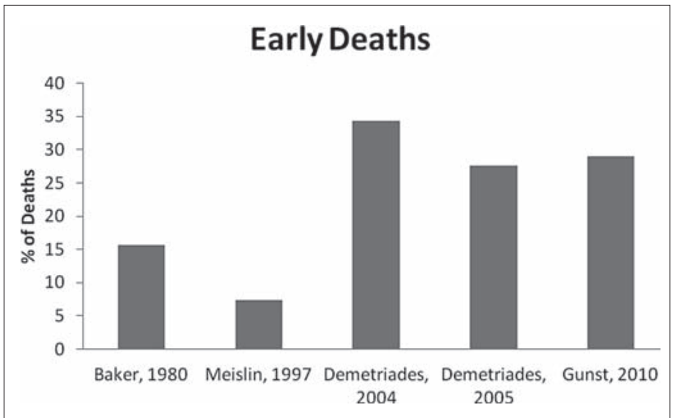

Figure 2. Studies reviewing early deaths (12, 13, 15, 16, 19).

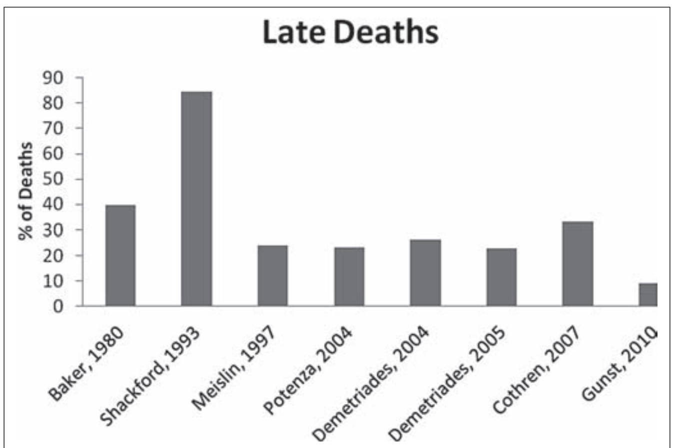

Figure 3. Studies reviewing late deaths (12, 13, 15, 16, 19, 22–24).

Deaths among trauma patients after discharge have largely remained overlooked in the trauma literature. This is due in large part to the difficulty of follow-up in the trauma patient population. First, regionalized trauma networks often mean that patients are transported farther from home for their initial episode of care at designated trauma centers. Second, trauma patients are typically younger individuals who are more mobile in pursuit of work or education. However, several studies have shown that trauma patients have an increased risk of mortality after discharge. Follow-up methods have varied, but the most commonly used are trauma registries, hospital databases, and patient records from single institutions. Combined with a lack of communication between medical record systems, single-institution studies are likely to miss patients who pursue follow-up care closer to home at a different hospital. In order to capture higher percentages of the study population, particularly over longer periods of time, telephone interviews or mail surveys are commonly utilized. More recently, trauma researchers have employed vital statistics records and Social Security data as a means of capturing high percentages of patients while also obtaining cause-of-death data (27–29).

In a study of data from 1991 to 1993, Mullins et al reported an in-hospital mortality rate of 12.1 per 100,000 for trauma deaths. This increased to 14.1 per 100,000 when including patients who died within 30 days of discharge (30). Among injured Medicare patients discharged to home, the 30-day mortality ranged from 1.9% to 2.3% (31). In 2004, Clark and colleagues reported that among injured Medicare patients, 30-day mortality was 7.5% compared with 3.7% in-hospital mortality (6). In 2006, MacKenzie et al reported a case fatality rate for in-hospital deaths of 7.6%, which remained stable for 30 days but increased to 10.4% at 1 year (32). In 2008, Gorra et al reported 30-day mortality rates of 4.2% to 5.4% among injured Medicare patients discharged to a long-term care facility (31). A 2010 study by Claridge and colleagues reported a mortality rate of 3.6% at 30 days, 4.1% at 90 days, 5.5% at 1 year, and 8.1% over the entire study period (33). In 2011, Davidson et al demonstrated 9.8% mortality at 1 year and 16% 3-year cumulative mortality (34). The multiinstitutional prospective National Study on Costs and Outcomes of Trauma evaluated patients up to 1 year after discharge. In this study, MacKenzie et al reported an in-hospital mortality rate of 21.3%, but a further 2.6% were dead at 3 months, and an additional 2.2% were dead by 12 months (35). Similarly, in 2005, Wright and colleagues reported a 5-year mortality rate of 22.1% in trauma patients admitted to an intensive care unit during their initial hospitalization (36). In 2011, Timmers et al reported a 1-year mortality rate of 17%, which increased to 29% between 6 and 11 years (37). Finally, our recently published study utilizing Social Security data showed that almost half of the deaths in trauma patients occurred after discharge from the trauma center (27). All these studies are consistent in their findings that the risk of death among trauma patients remains elevated for months to years afterward.

Table. Causes of death by timing category

Immediate and early deaths	Late deaths	Postdischarge
Brain injury	Infection	Cardiovascular disease
Hemorrhage	Multiple-organ failure	Second major trauma
	Brain injury	Neurologic disease
	Hemorrhage	Malignancy

CAUSES OF DEATH

Several studies have investigated the causes of death in trauma patients. Baker et al found that brain injury accounted for a majority of deaths, at 50% (13). Heart or aortic injury (17%), hemorrhage (12%), sepsis (10%), lung injury (6%), burn (3%), and liver injury (2%) accounted for the remainder. The majority of patients with major cardiac, vascular, or liver injury died of hemorrhage. Shackford and colleagues also found that head injury was the most common cause of death, and when combined with spinal cord injury, neurologic injuries were responsible for 49% of deaths (24). On autopsy, secondary brain injury, defined as diffuse cerebral edema; herniation; or cerebral necrosis due to hypoxia, hypotension, or cerebral edema that followed the primary injury was present in just over half of neurotrauma cases. Almost a third (31%) of victims died of hemorrhage in the chest, the abdomen, or both cavities. Other causes of death included asphyxia in 6%, cardiac arrest in 4%, sepsis in 3%, and pneumonia in 2%. The *Table* lists the most common causes of death for each time interval. Immediate and early deaths are considered together, given the similar etiologies.

In Trunkey and Lim's initial case series in 1972, 45% of the patients in the immediate death category died of irreversible brain injury, such as lacerations of the brain, brain stem, or spinal cord, and 35% died due to hemorrhage resulting from injuries to the heart, aorta, liver, lungs, and pelvic fractures (21). Similarly, Meislin et al showed that for death within 1 hour of injury, 46% were neurologic injuries and 31% were due to circulatory collapse resulting from hemorrhage (19). Likewise, work from Sauaia et al showed that among those dead on the scene, 42% died from central nervous system injuries, 39% from exsanguination, and 7% from organ failure (18). These studies are consistent in reporting that the two most common causes of immediate deaths are head injuries and hemorrhage.

The cause of early trauma deaths is similar to that of immediate deaths and likely represents less catastrophic injuries or better prehospital care and shorter transport times to trauma centers. As described by Trunkey and Lim, the causes of death in this group include major internal hemorrhages of the head, respiratory system, or abdominal organs or multiple minor injuries resulting in severe blood loss (21). Sauaia et al reported that among trauma deaths within 48 hours of injury, exsanguination was the most common cause (51%) due to injuries to the liver, heart, or major blood vessels (7). This was particularly true for patients with penetrating injuries. Central nervous system injury was the second most common cause of death, including brain lacerations, contusions, and subdural hemorrhages (18). Meislin et al showed that neurologic injuries and circulatory collapse or hemorrhage accounted for over 80% of early deaths (19). Baker and colleagues showed that most of the deaths due to head injuries were within the first 2 days after injury (13).

Trunkey reported that 80% of late deaths in the hospital were due to infections or multiple organ failure (14). Similarly, Baker found that 78% of deaths after 7 days were due to sepsis and multiple organ failure (13). Cowley indicated that the most common causes of death in this group were overwhelming infection and irreversible head injuries (26). Sauaia et al reported that for deaths occurring after 1 week postinjury, organ failure claimed the majority of patients (61%) (18). More recently, Meislin et al reported that for the group dying within 24 to 48 hours, 45% died of neurologic injury, 42% of circulatory collapse or hemorrhage, and 9% of multiple organ failure (19). Similarly, for the group dying 2 days to 3 weeks after injury, 48% died of neurologic injury, 35% of circulatory collapse or hemorrhage, and 16% of multiple organ failure. These studies indicate that head injuries and hemorrhage remain important causes of death among patients who survive the first 24 hours, but multiple organ failure becomes more prominent with the passage of time.

Causes of death after discharge from trauma centers are less well studied. This is due, in part, to the difficulties of follow-up. Mullins evaluated cause-of-death codes reported on death certificates for injured patients who died of nontraumatic causes during their hospital stay and within 30 days after discharge (30). Of 1174 postdischarge deaths, 15% were due to neoplasms, 12% to cerebrovascular disease, 11% to cardiovascular disease, 11% to ischemic heart disease, 9% to chronic obstructive pulmonary disease, and 8% to acute myocardial infarction. Another 20% were due to a myriad of other causes. In a German study, Probst and colleagues described in-hospital and postdischarge causes of death for trauma patients (38). While in-hospital causes of death mirrored those previously discussed, postdischarge deaths included cardiovascular disease in 23%, a second major trauma in 19%, neurologic disease in 16%, suicide in 10%, and malignancies in 6%. Furthermore, trauma patients had increased mortality compared with the general population during the first year after injury. The mortality rates were more closely approximated during years 2 to 10 after injury. Claridge and colleagues classified deaths as trauma related in 33%, possibly related in 23%, and unrelated in 44% (33). Additionally, mortality after discharge was more likely trauma related in younger patients. The authors found that most deaths within the first year after injury were attributable to trauma, after which chronic diseases increased mortality. These studies indicate that postdischarge deaths among trauma patients are related to common chronic diseases within the population. However, the impact of injuries on the outcome of these chronic diseases remains unknown.

CONCLUSION

Three important conclusions can be drawn from this review. First, deaths occurring within minutes or a few hours of injury are largely unchanged, reflecting the devastating nature of injures to the central nervous and cardiovascular systems. Late deaths due to multiple organ failure and sepsis, however, have declined dramatically. Second, the causes of death in this patient population, i.e., those with severe head injuries and hemorrhage, remain persistent. Finally, a large number of deaths in trauma patients that occur after discharge may be related to nontraumatic causes. Reasons for the increased risk of death from nontraumatic causes after discharge need to be studied further.

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